# ADVANCES IN DOMAIN CONNECTIVITY FOR OVERSET GRIDS USING THE X-RAYS APPROACH

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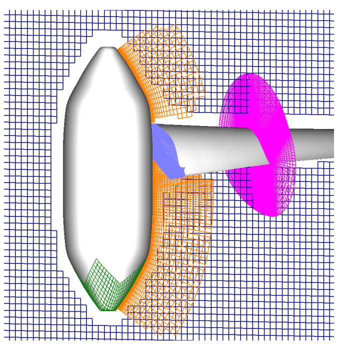
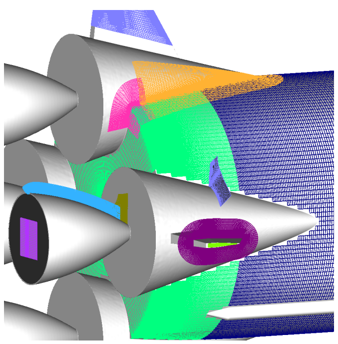
## OVERVIEW

- Brief review of overset grids and hole-cutting
- Automatic hole cutter closure
- Adaptive X-rays
- Automatic hole boundary adjustment
- Comparisons, test cases
- Summary and conclusions



## OVERSET GRIDS AND HOLE-CUTTING





**Minimum hole**
Identification of grid points inside solid boundaries

**Offset hole**
Create appropriate offset from wall so that interpolation occurs away from high gradient regions near wall

**Field equations not solved at blanked points**



## DOMAIN CONNECTIVITY / OVERSET ASSEMBLY

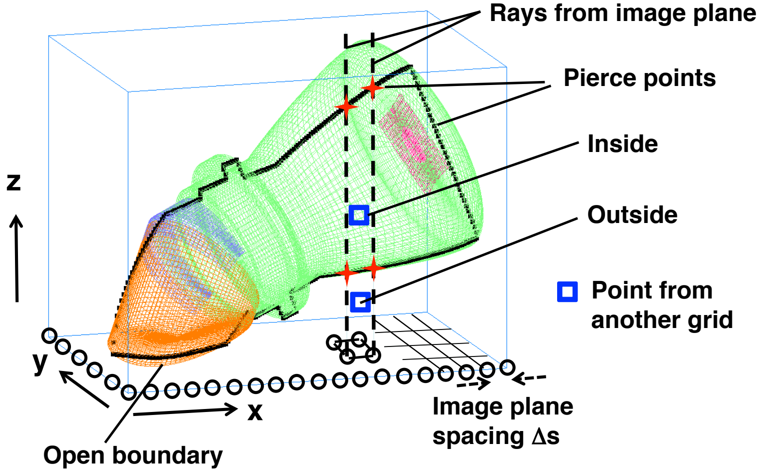
**Hole Points Identification Methods (partial list)**
- Cartesian hole map
- Line of sight
- X-rays
- Implicit hole-cutting

**Stencil Search Methods (partial list)**
- Cartesian inverse maps
- Multi-level spatial partitions (ADT, octree, …)

**Software (partial list)**
- PEGASUS5
- OVERFLOW/DCF
- SUGGAR++
- PUNDIT
- OVERTURE

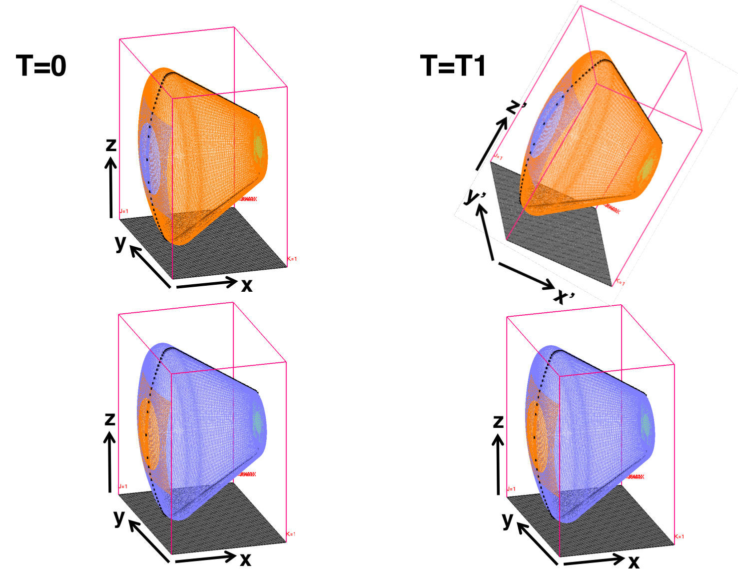
## ORIGINAL X-RAYS METHOD (OVERFLOW/DCF)

**Meakin, AIAA Paper 2001-2537**



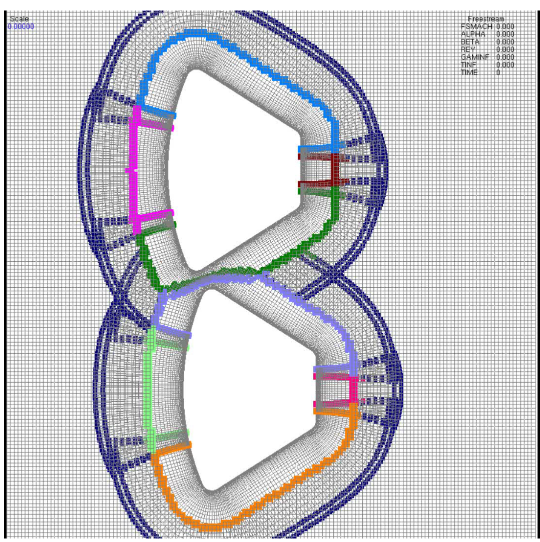



## X-RAYS FOR RELATIVE MOTION PROBLEMS






## RELATIVE MOTION EXAMPLE

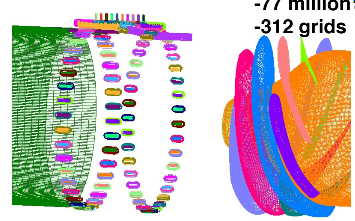




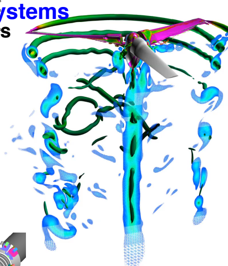
## APPLICATIONS USING X-RAYS APPROACH

**Flowliner and Liquid Rocket Subsystems**

-77 million pts
-312 grids

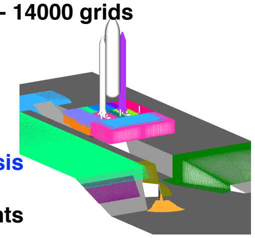


**Rotor Blades in Hover**



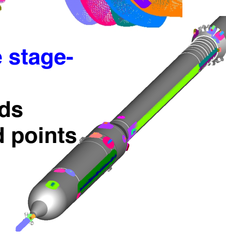
Baseline
- 35 million pts
- 58 grids

Adapted
- 660 million pts
- 14000 grids



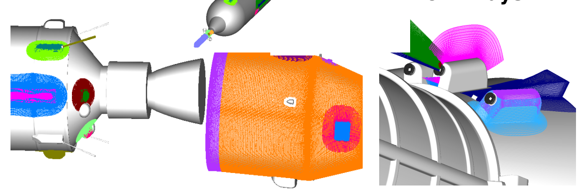
**Launch vehicle stage-separation**

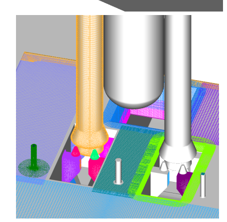
224 volume grids
267 million grid points
142 X-rays



**Launch Site Analysis**

129 volume grids
92 million grid points
32 X-rays





## PROS AND CONS OF ORIGINAL X-RAYS APPROACH

**PROS**

- Fast hole cutting => excellent for relative motion problems
- Low memory requirements (2-D map + pierce points)

**CONS – manual inputs needed at the start**

- Identify components
- Close component open boundaries (tedious)
- Specify grid subsets to be cut by each X-ray (tedious and error prone)
- Specify uniform X-ray image plane spacing (very large X-ray files in tight-gap cases)
- Specify constant offset for each minimum hole (variable offset preferred for better interpolation)



## OBJECTIVES

Explore methods to:

- reduce required user expertise, input effort, time
- automatically generate appropriate variable offset hole boundaries

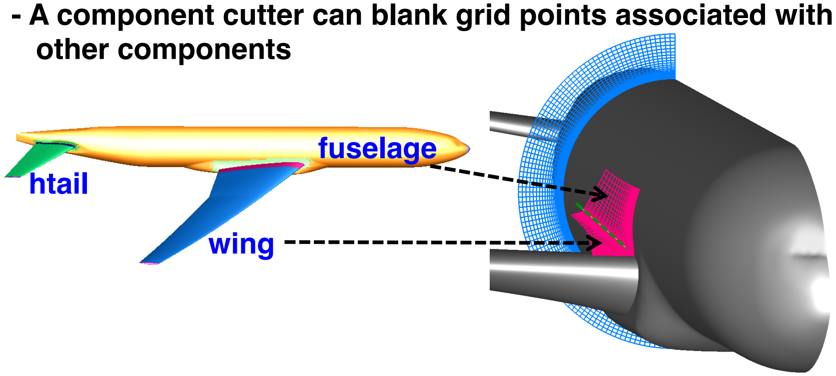
Maintain algorithmic efficiency of original X-ray scheme for relative motion problems

Develop code in library form for easy interface with other software modules



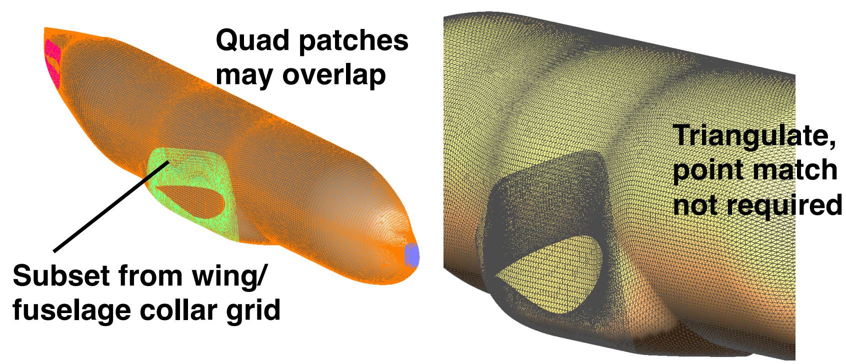
## COMPONENT DEFINITION

- Typically a geometric part of a configuration
- Defined by a collection of surfaces that may or may not form a closed volume
- Each grid point in a near-body volume grid is associated with a component
- A component cutter can blank grid points associated with other components






## COMPONENT SURFACE DEFINITION




Defined via solid wall boundary conditions on surface subsets (additional tag to indicate component ID)

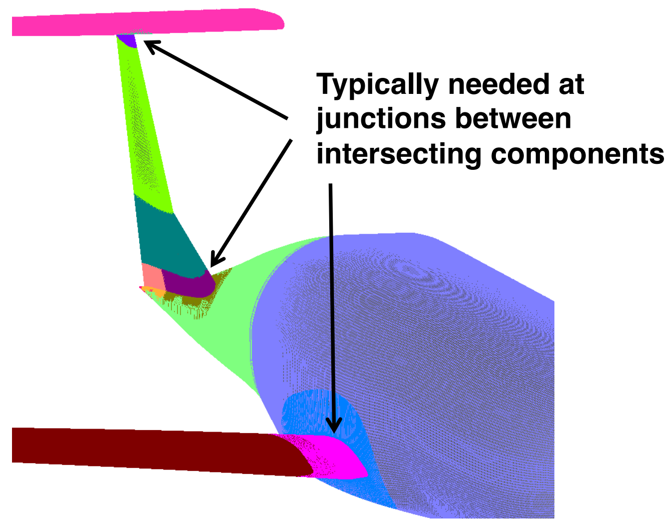
or

Defined via surface grid cell tags from CAD component information (future implementation)

## AUTOMATIC HOLE-CUTTER CLOSURE

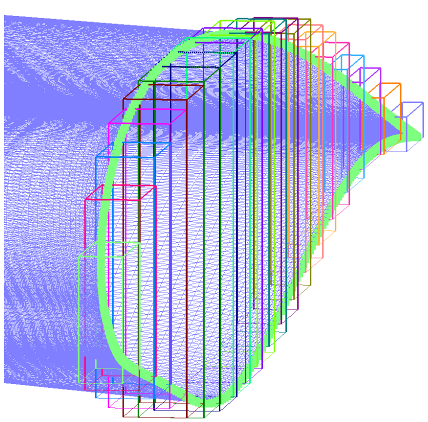


## COMPONENT OPEN BOUNDARY CLOSURE



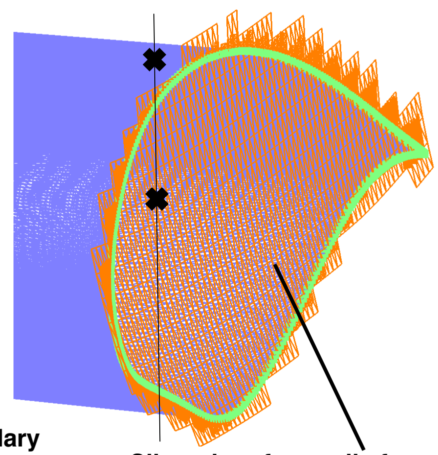



## WING ROOT CLOSURE



Bounding box set over open boundary (used to clip cells from other components)

Obtained by sub-dividing longest direction of open boundary bounding box

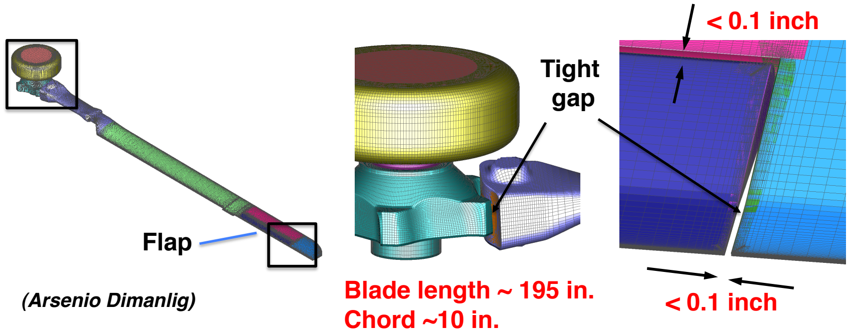


Clipped surface cells from fuselage used to provide closure (no need to be point matched)



## ADAPTIVE X-RAYS

## PROBLEMS WITH UNIFORM X-RAY MAP IN ORIGINAL SCHEME



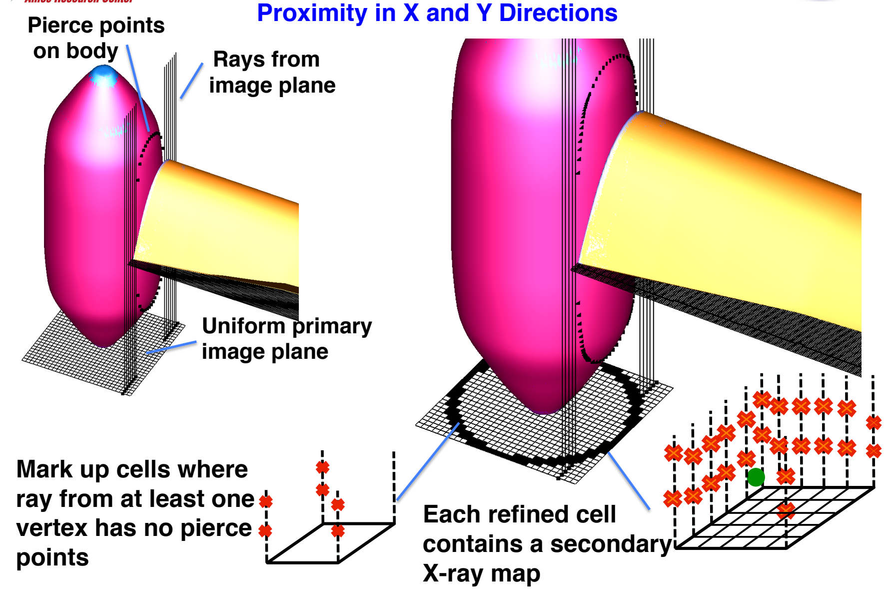

Extremely fine X-ray maps are sometimes needed in tight gaps
=> very large X-ray file size due to uniform spacing requirement

Blade and flap - 10 X-rays
- X-ray file size = 185MB (about 1/4 size of grid file)



## ADAPTIVE SECONDARY X-RAY MAP

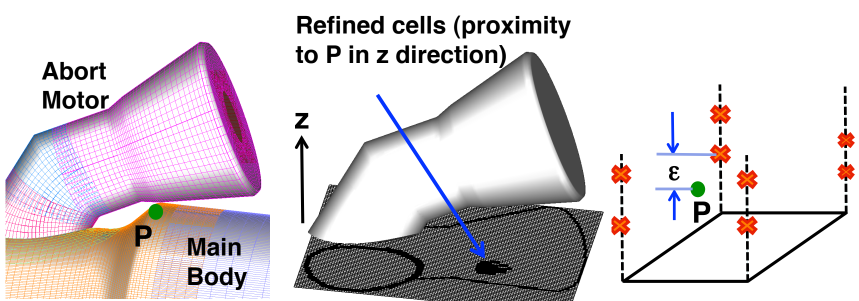
### Proximity in X and Y Directions






## ADAPTIVE SECONDARY X-RAY MAP

### Proximity in Z Direction

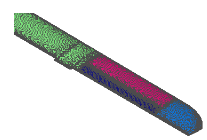



Given component primary X-ray map, locate cells in image plane for surface grid points P from all other components

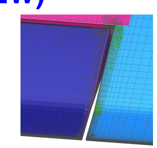
Mark cell for refinement if z-coordinate of P is within ε of z-coordinates of any pierce points from rays bounding the cell ($\varepsilon \sim \Delta s$ of primary X-ray map)

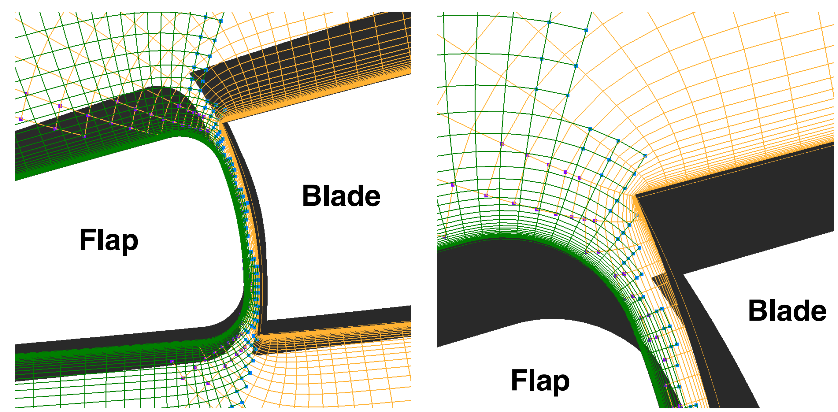


## ADJUSTED HOLE BOUNDARIES FOR ROTOR FLAP TIGHT GAP PROBLEM (SIDE VIEW)

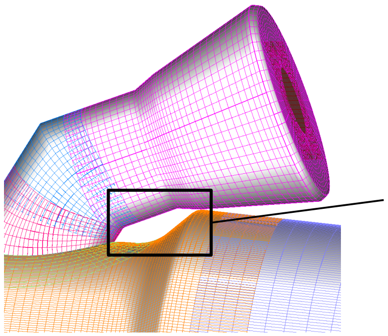


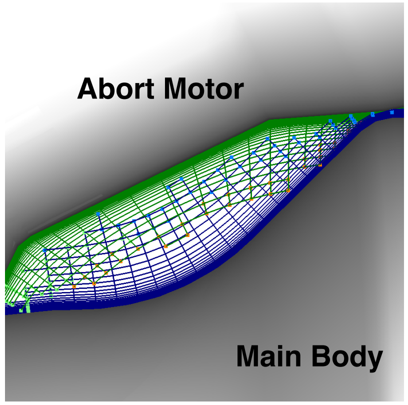
**X-rays file size**
Original = 186 MB
Adaptive = 63 MB





## ADJUSTED HOLE BOUNDARIES FOR ABORT MOTOR AND MAIN BODY PROXIMITY PROBLEM






**X-rays file size**

Original = 15.3 MB

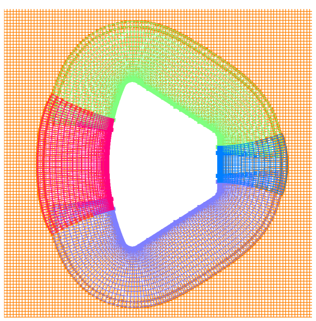
Adaptive = 2.9 MB



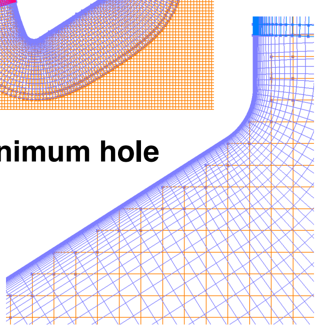
## AUTOMATIC HOLE BOUNDARY ADJUSTMENT

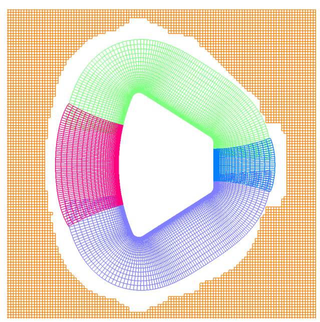


## EXTREMES OF HOLE BOUNDARIES



Minimum hole

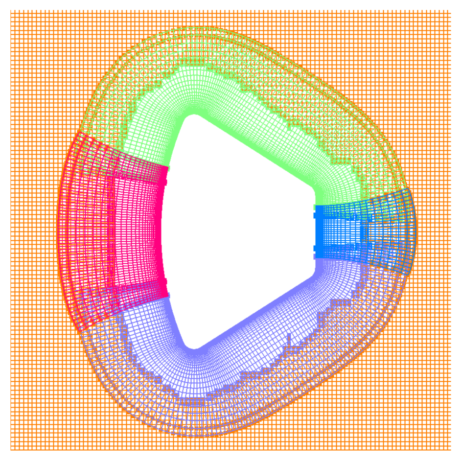




No overlap



## ACCEPTABLE HOLE BOUNDARIES



**Ideal scenario**

Interpolation occurs between cells of comparable attributes (cell volume, aspect ratio, orientation)

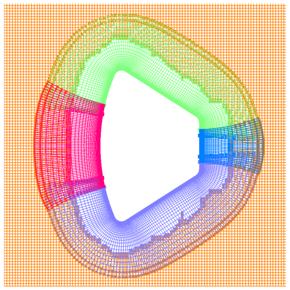
**X-rays approach**

Interpolation occurs away from solid wall boundaries (high gradient regions)

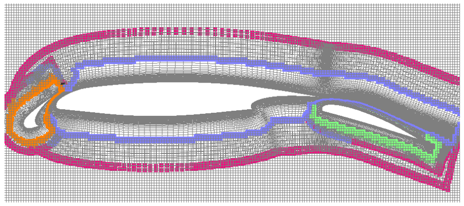
**Many acceptable solutions**

**Aero loads sensitivity?**

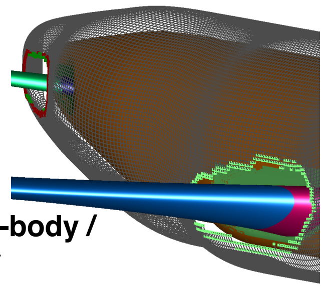
## TYPES OF HOLE BOUNDARIES



Near-body / Off-body



Disjoint Near-body / Near-body



Intersecting Near-body / Near-body



## HOLE BOUNDARY ADJUSTMENT STRATEGY

**Step 1**
Use a wall-distance function to get first estimate of hole boundary location away from minimum hole

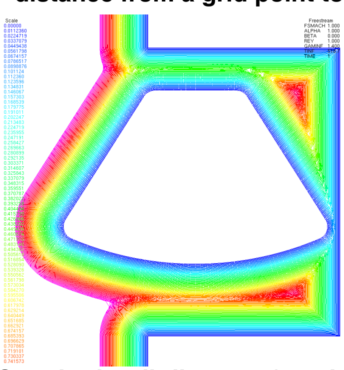
**Step 2**
Iterate on hole boundary using orphan points removal as objective



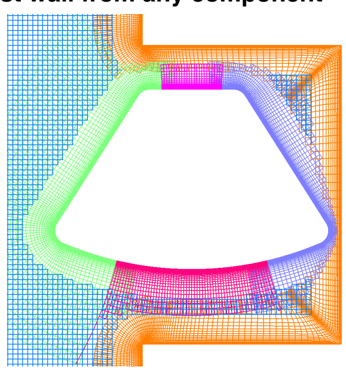
## STEP 1: HOLE BOUNDARY ESTIMATE USING WALL-DISTANCE FUNCTION

Objective: get hole boundary away from minimum hole

Standard wall distance function Dw computed in flow solvers with popular turbulence models (SA, k-$\omega$, SST)
= distance from a grid point to closest wall from any component



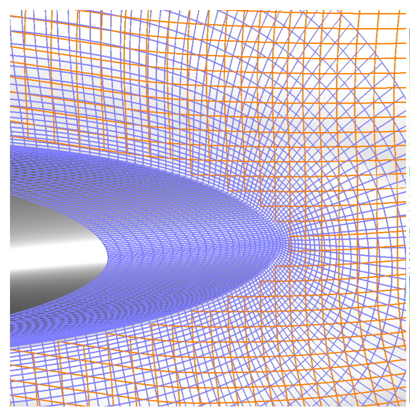
Standard wall-distance function



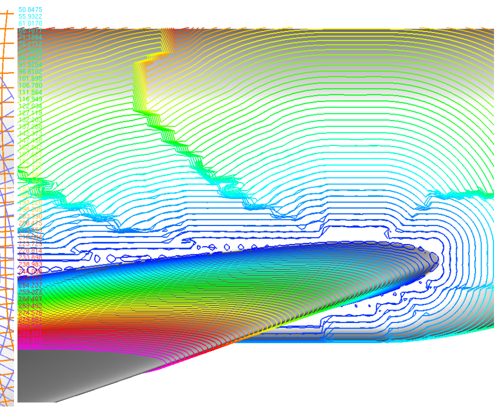
Hole boundary first estimate



## INTERSECTING COMPONENTS



Minimum hole – need to expand hole but standard wall-distance function is zero everywhere on surface

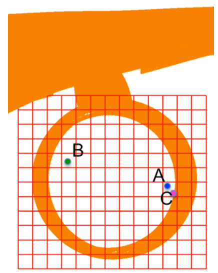


Need a wall-distance function that is sensitive to distance to all components except self

## DUAL WALL-DISTANCE FUNCTION

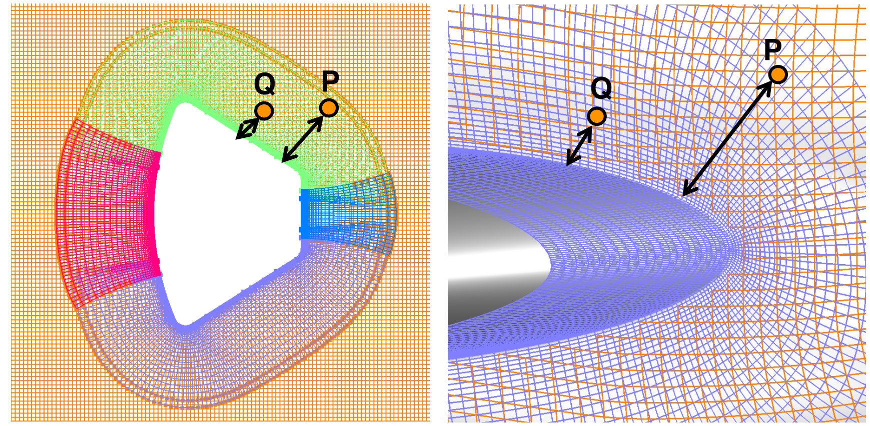
**Dn – Closest distance from point to wall of associated component**
- Defined for near-body grids only
- Distance along ray from wall

**Df – Closest distance from point to wall of any unassociated component**
- Defined for near and off-body grids
- Need to return the ID of the closest component (Cn)
- An approximation may be sufficient (pixel map analogy algorithm)






## HOLE BOUNDARY OFFSET ESTIMATE USING DUAL WALL-DISTANCE FUNCTION




Blank point if it is less than about half way from component surface to
- component grid outer boundary
- collar grid outer boundary



## STEP 2: HOLE BOUNDARY ITERATION TO REMOVE ORPHAN POINTS

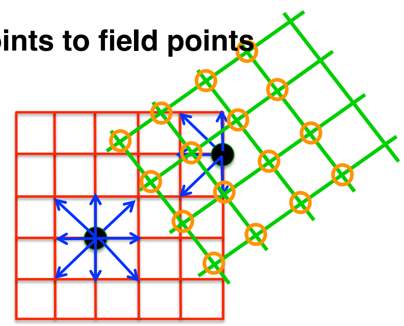
Objective: reduce number of orphan points to same number as that in minimum hole

- Store interpolation stencils for fringe points visited to minimize search at each iteration

**Orphan point in interior**
Convert neighboring blanked points to field points

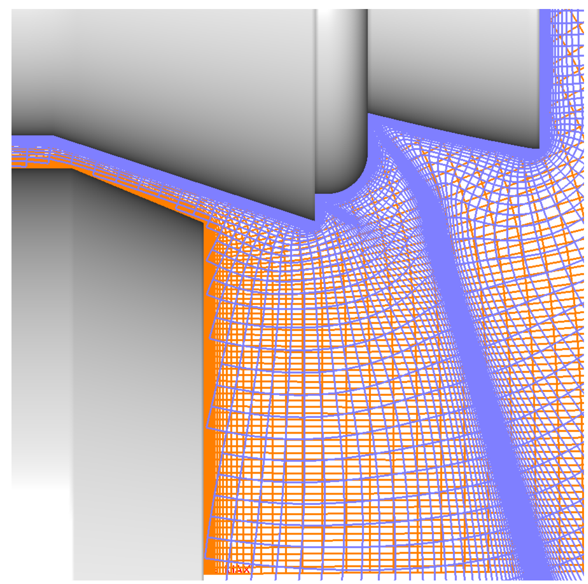
**Orphan point on grid boundary**
Convert blanked points to field points near donor grid cell

**Field point conversion not allowed at minimum hole points**

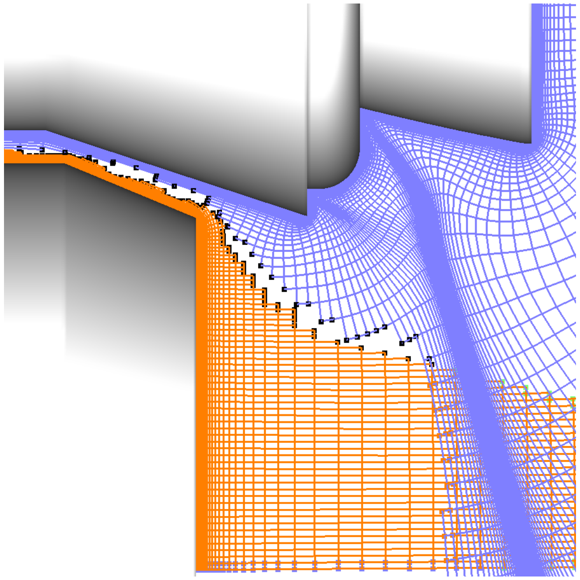




## HOLE BOUNDARY AFTER MINIMUM HOLECUT

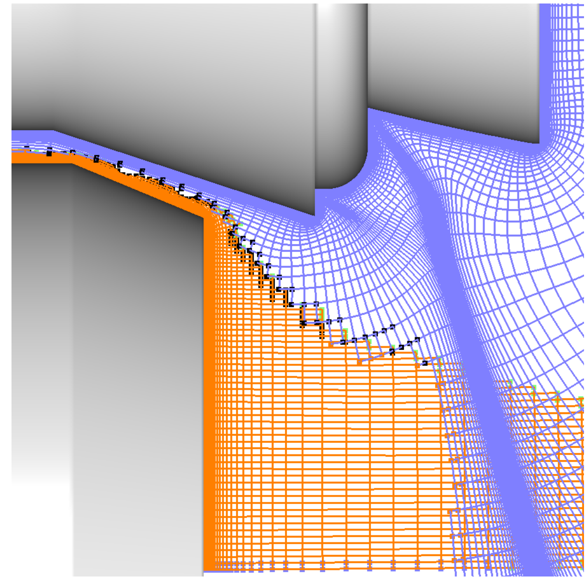


## HOLE BOUNDARY AFTER WALL-DISTANCE FUNCTION OFFSET ESTIMATE



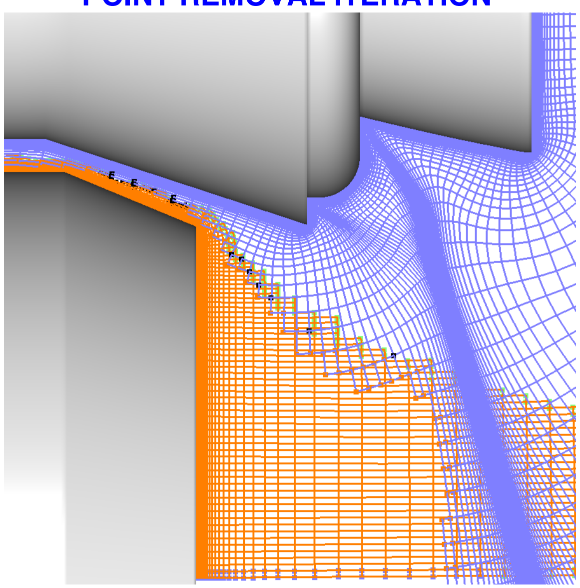


## HOLE BOUNDARY AFTER 1ST ORPHAN POINT REMOVAL ITERATION



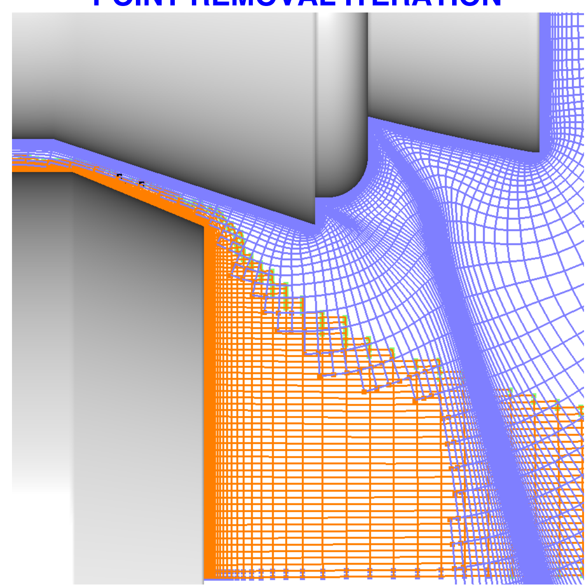


## HOLE BOUNDARY AFTER 2nd ORPHAN POINT REMOVAL ITERATION



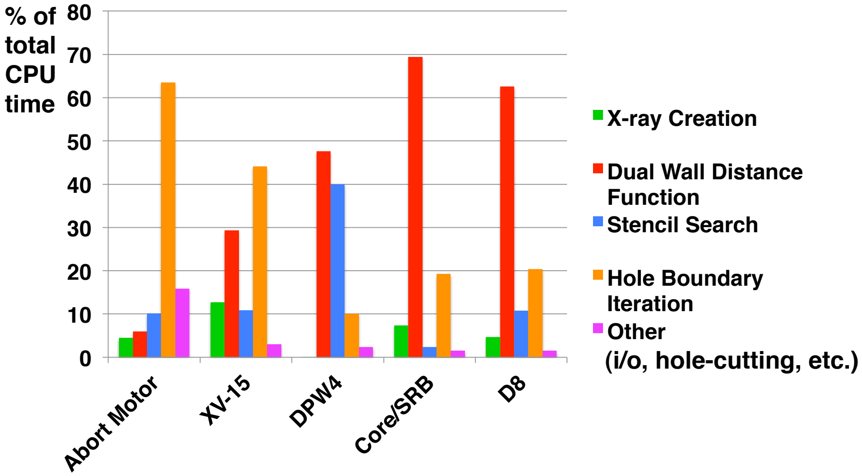


## HOLE BOUNDARY AFTER 3rd ORPHAN POINT REMOVAL ITERATION



## CPU TIMES (PERCENT OF TOTAL) FOR VARIOUS STEPS OF DOMAIN CONNECTIVITY PROCESS

(Not fully balanced OpenMP)




4.4m 9.9m 16m 28.6m 77.7m (# Grid points, m=$10^6$)



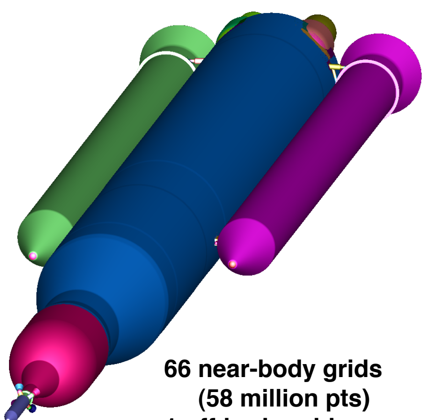
## TEST CASES

- Current software
  - Chimera Components Connectivity Library (C3LIB)
  - Chimera Components Connectivity Program (C3P)
- Check variable offset hole boundary quality
  - fringe points away from walls
- Comparison of current scheme (C3P) with original X-rays (OVERFLOW/DCF)
  - aerodynamic loads
  - CPU time
  - user time

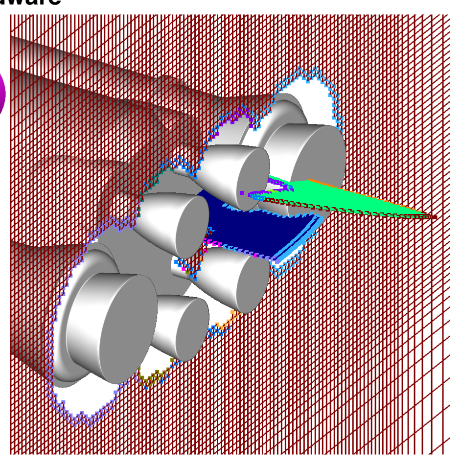


## LAUNCH VEHICLE (LV)

Core stage , RSRB's, MPCV, abort motors, forward and aft attach hardware



66 near-body grids
(58 million pts)
1 off-body grid
(7 million pts)
25 components



C3P execution time
= 15.3 min (8 procs)

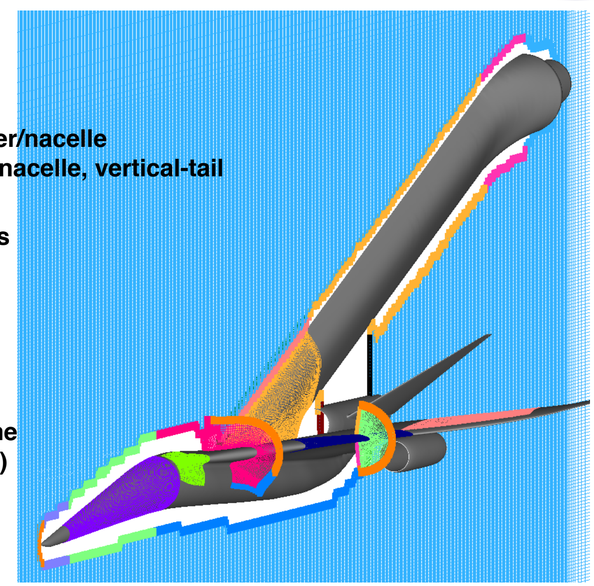


## LOCKHEED MARTIN N+2 SUPERSONIC MODEL

Fuselage
Wing
Blade mount
Lower wing diverter/nacelle
Upper wing pylon/nacelle, vertical-tail

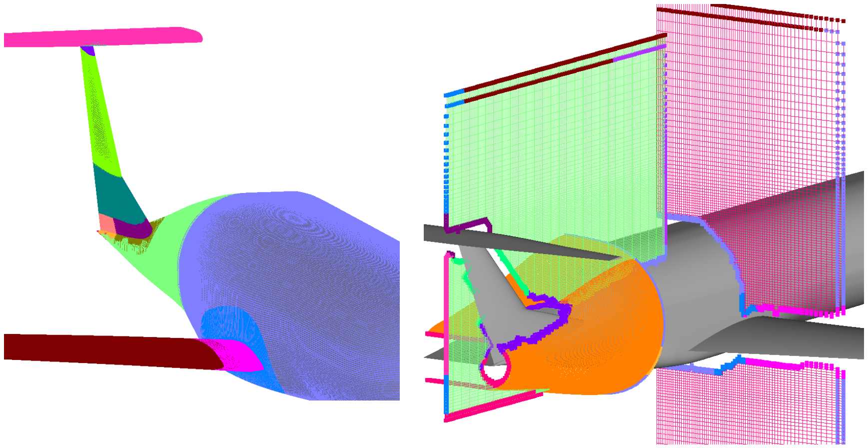
70 near-body grids
(15 million pts)
1 off-body grid
(37 million pts)
1 component

C3P execution time
= 5.7 min (8 procs)



## D8 DOUBLE BUBBLE AIRCRAFT

### 30 grids, 77.7 million grid points

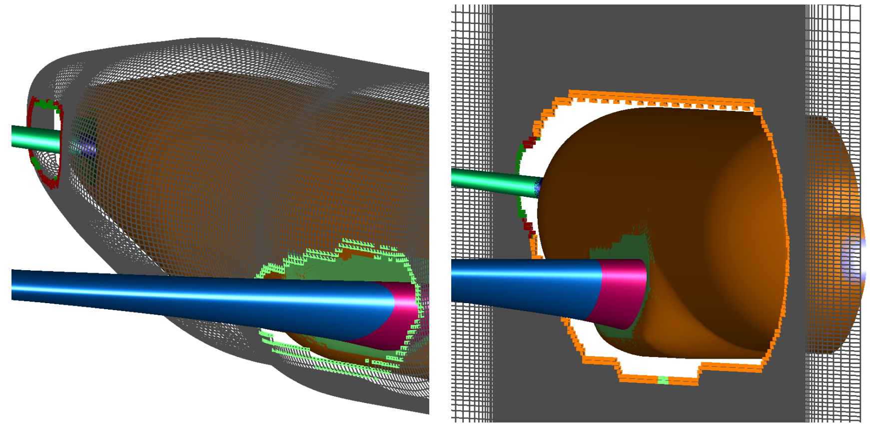


| | Lift coef. | Drag coef. | Pitch moment coef. |
|---|---|---|---|
| Original X-rays | 0.4560 | 0.0358 | -0.02898 |
| Improved X-rays | 0.4625 (1.4% diff) | 0.0360 (0.6% diff) | -0.02967 (2.3% diff) |



## DRAG PREDICTION WORKSHOP (DPW4)

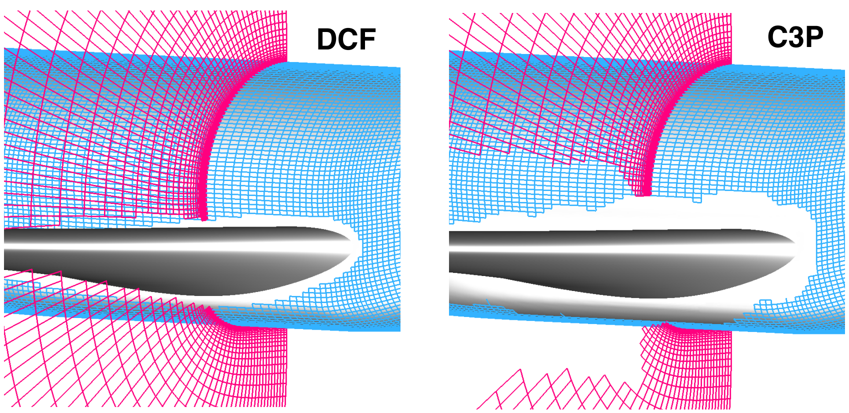
### 17 grids, 16.8 million grid points
### Various grid slices from C3P





## DRAG PREDICTION WORKSHOP (DPW4)

### 17 grids, 16.8 million grid points
### Comparison between OVERFLOW/DCF and C3P




| | Lift coef. | Drag coef. | Pitch moment coef. |
|---|---|---|---|
| Original X-rays | 0.4852 | 0.02741 | -0.02898 |
| Improved X-rays | 0.4862 (0.2% diff) | 0.02736 (0.2% diff) | -0.02967 (2.3% diff) |



## CPU AND USER TIME COMPARISON

### CPU TIME

OVERFLOW/DCF (original) – 8 MPI processes
C3P (improve) – 8 OpenMP threads

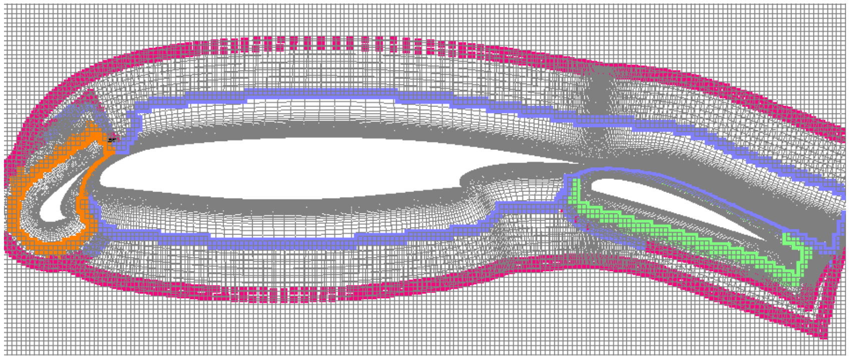
| Test Case | # Grid pts ($x10^6$) | OVERFLOW (Standard Distance Fun.) | C3P (Dual Distance Fun.) |
|---|---|---|---|
| DPW4 | 16.8 | 1.1 min. | 1.75 min. (+54%) |
| D8 | 77.7 | 14 min. | 19.9 min. (+42%) |

**New code is ~ 50% more expensive compared to original but it is also doing more work**

### USER INPUT PREPARATION TIME

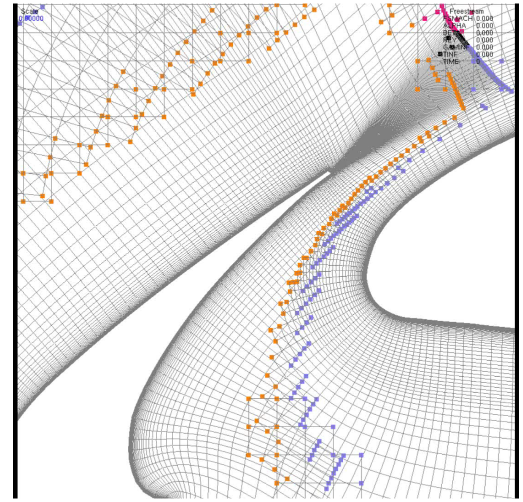
| Test Case | # Grid pts ($x10^6$) | # Grids | # X-rays | OVERFLOW | C3P | Speed up |
|---|---|---|---|---|---|---|
| DPW4 | 16.8 | 17 | 3 | 30 – 120 min. | 10 – 20 min. | 3x – 6x |
| D8 | 77.7 | 30 | 4 | 0.5 – 1.5 days | 20 – 30 min. | 36x – 72x |
| LV | 65 | 67 | 25 | 1 – 3 days | 45 – 90 min. | 32x – 48x |

## UNSTEADY 2-D HIGH-LIFT SYSTEM





## UNSTEADY 2-D HIGH-LIFT SYSTEM (SLAT REGION)



Spatially variable offset during relative motion simulation



## SUMMARY AND CONCLUSIONS

### Minimum Hole Automation

- Hole-cutter open boundary closure
- Determination of grid points to be considered for blanking
- Adaptive X-rays to handle components in close proximity economically

### Adjusted Hole Automation

- Dual wall distance function to get first estimate
- Further adjustments using orphan points removal
- Spatially variable offset for relative motion problems

### Comparison with Original X-rays

- Preliminary tests show aero loads are comparable
- CPU time is about 50% more expensive (could be further reduced)
- Human effort, time, and expertise reduced significantly (factor of ~ 3 - 70)



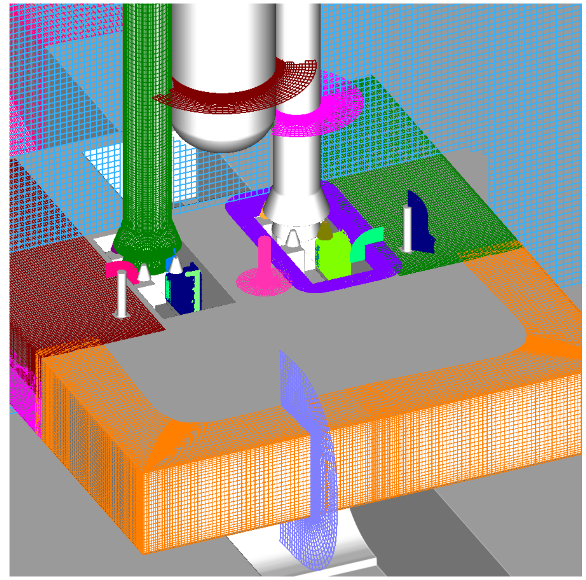
## BACKUPS

## FUTURE WORK

- Implement multiple entry points into C3P
- Improve hole boundary iterations to get orphan points back to same number as that for minimum hole
- Improve optimization and load balancing further
  - Dual wall-distance function
  - Stencil search
  - MPI
- Systematic study on sensitivity of aerodynamic loads to hole boundary locations



## OVERSET GRIDS AND HOLE-CUTTING



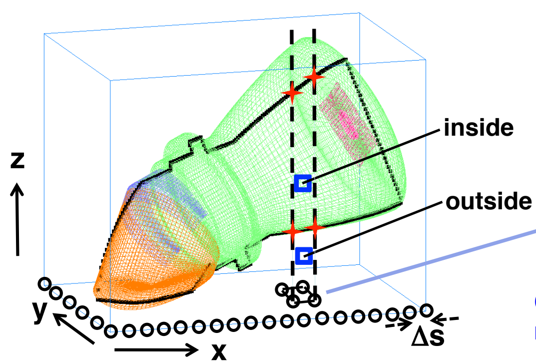
**Minimum hole**
Identification of grid points inside solid boundaries

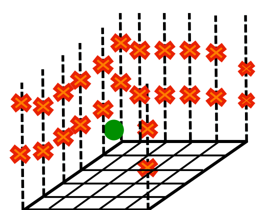
**Offset hole**
Create appropriate offset from wall so that interpolation occurs away from high gradient regions near wall

**Field equations not solved at blanked points**



## MINIMUM HOLE CUT USING ADAPTIVE X-RAYS



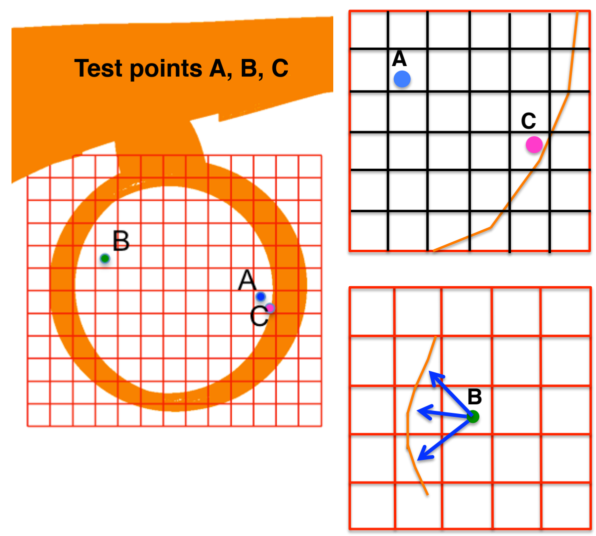



Create secondary X-ray map in each refined cell

Given test point (xp,yp,zp)
1. Look up cell in primary X-ray using xp, yp
2. If not refined cell, do inside/outside test on primary map
3. If refined cell, do inside/outside test in cell secondary X-ray map



## APPROXIMATE COMPUTATION OF DUAL WALL-DISTANCE (pixel map / compound eye analogy)



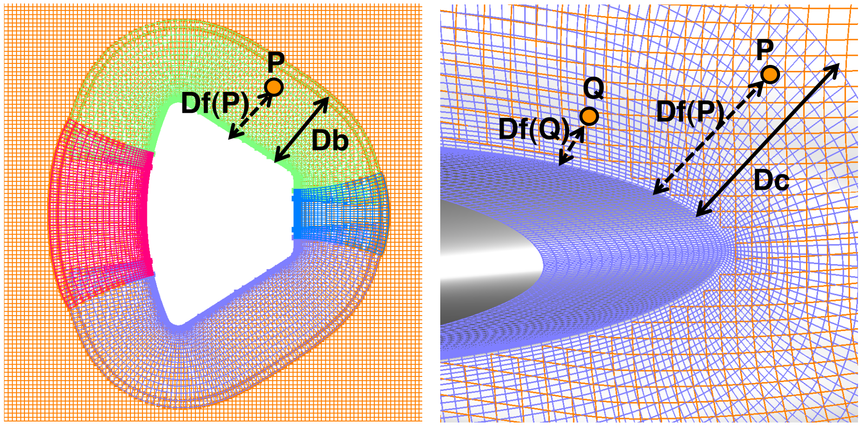

Level-1 3-D Cartesian map over component

Level-2 3-D Cartesian map over cells with walls

Cw = closest cell containing a wall located by radial search in index space

Df = distance from pt to centroid of Cw

# HOLE BOUNDARY OFFSET ESTIMATE USING DUAL WALL-DISTANCE FUNCTION




**Given point from another component, blank point if**

**Df < Rb x Db** **Df < Rb x Dc**

**Rb = 0.5 (can be modified by user if needed)**